A Local Potential for $\alpha-\alpha$ Interaction

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Abstract: An attractive local potential of cosh type is applied to $\alpha+\alpha$ scattering. The experimental phase shifts are reproduced fairly well with an L- and energy- independent deep attractive potential over a wide energy region of $E_{cm}\leq 60$ MeV.

The $\alpha+\alpha$ scattering is a typical composite particle scattering and much attention has been paid to stuty of the $\alpha-\alpha$ interaction. Many attempts[1-7] to obtain a phenomenological potential have been done through a systematic phase shift analysis at low energies. These studies have shown that a potential should be repulsive inside and attractive with L (angular momentum) - dependence outside. An L-dependence in the potential is indispensable and it is impossible to reproduce the experimental phase shifts with any potential without introducing L-dependence. This feature of the potential is founded by the microscopic model.

The $\alpha+\alpha$ scattering has also been investigated by many authors[8-14] with the resonating group method from the microscopic point of view by taking account of the Pauli principle completely. The experimental phase shifts are excellently well reproduced by the resonating group method. It has been made clear that the exchange kernel due to the Pauli principle plays an important role. An equivalent local potential which gives the same wave function as the resonating group method has the following characteristic: inside strong repulsive, outside attractive and an L-dependence indicated by stronger attractive and weaker repulsion for higher L. Here the Pauli principle plays an essentially important role in producing both the repulsive potential and the L-dependent attractive one. This characteristic is in accordance with the phenomenological potential. From this situation it has been considered that no potential, which is common to all L, exists.

On the other hand Igo[15] has shown that the phase shift can be well reproduced over a wide energy region with an L-independent attractive potential of Woods-Saxon type. This potential, however, has not been considered realistic because a repulsive core does not exist in the inner region. In the present paper we show that the $\alpha+\alpha$ scattering can be well reproduced with a local potential of cosh type. The potential we adopt is given by

$$V(r)=V_0\frac{1+\cosh\left(\frac{R}{a}\right)}{\cosh\left(\frac{r}{a}\right)+\cosh\left(\frac{R}{a}\right)}.$$

This potential was originally applied to study of α-cluster structure in sd-shell nuclei.[16] It is quite interesting to extend this potential to scattering problem.

We try to search potential parameters which reproduce all the phase shift of the $\alpha+\alpha$

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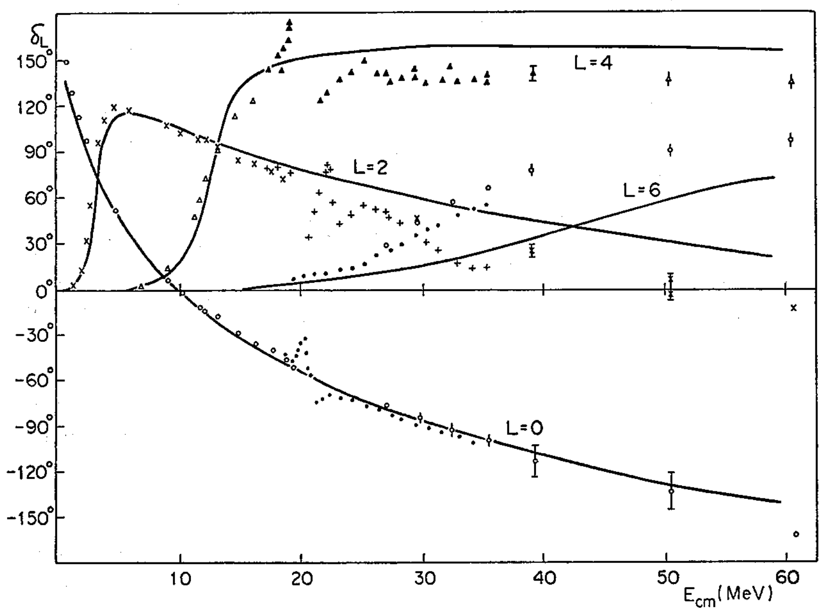

Fig. 1. Phase shifts of the $\alpha+\alpha$ scattering. The solid line represents the calculated results. As the experimental phase shifts, only representative points are shown. See Ref. 14) for more detailed data at $E_{cm}\lesssim 20$ MeV. The plots ●, + and ▲ are taken from Ref. 18).

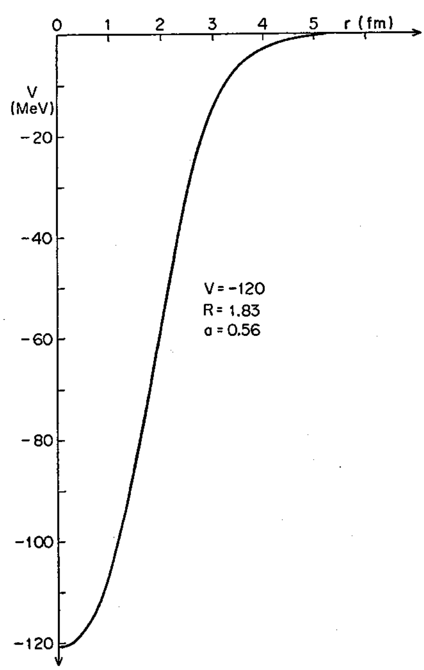

Fig. 2. Potential of the $\alpha+\alpha$ scattering.

scattering over a wide energy region. The Coulomb potential is assumed to be of a uniformly charged sphere of radius $R_c=2.22$ fm. First we try to fit the experimental phase shift by varying V_0 only with fixed values of $a=0.56$ and $R=1.75$. Through a grid search of V_0, V_0 around -120 MeV is found to be most suitable. Although the phase shift for S, D and G waves calculated with the parameters agree with the data well at 20 MeV$\lesssim E_{cm}\lesssim$40 MeV, there appears a discrepancy with the data at lower energy of $E_{cm}<20$ MeV. So we further vary R in order to improve a fitting. The diffuseness parameter a is not necessary to be varied since $a=0.56$ is quite a suitable value. Eventually the resultant potential parameters which fit the experiment best are $V_0=-120.0$, $a=0.56$ and $R=1.83$.

The calculated phase shifts are shown in Fig. 1 compared with the data and the potential is displayed in Fig. 2. The phase shift of $L=0$ is reproduced excellently from lower energy to higher energy. For $L=2$ and 4 the agreement with the experiment is satisfactorily good, especially at lower energy including the resonance region. For $L=6$ a general trend of the phase shift is reproduced but a more attractive potential is necessary. At higher energy reaction channels open and an imaginary potential is necessary to be introduced. Thus it is found that an attractive local potential of cosh type can reproduce well the $\alpha+\alpha$ scattering. It is surprising that an energy- and L-independent potential can reproduce the phase shift of all L over a wide energy region.

The potential in Fig. 2 is deep and diffuseness is large. How can we understand this deep attractive potential based on the microscopic model? According to Saito[19] the resonating group method is approximated by the orthogonality condition model, which takes into account the Pauli principle by excluding the forbidden states. The forbidden states of the harmonic oscillator potential in the $\alpha+\alpha$ system is $0s$ and $1s$ states for $L=0$ and $0d$ state for $L=2$. The deeply bound states in the present potential, which is similar to the harmonic oscillator potential, resemble these forbidden states. Therefore these deeply bound states play the same role as the forbidden states for the scattering problem. An L-independent attractive deep potential can be considered as a simulation of the orthogonality condition and is compatible with the microscopic model. An attractive local potential is far simpler than the orthogonality condition model and seems to have an extensive applicability to heavier system.

In conclusion an attractive local potential of cosh type can describe the phase shift of the $\alpha+\alpha$ scattering very well over a wide energy region. This potential is justified from the microscopic point of view. A potential of cosh type may be widely applied to the composite particle scattering in the *sd*-shell region.

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